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METHODS OF PROSPECTING FOR KARST WATER IN HUNGARY

Dr Hubert Kessler

With the rapid industrialization of Hungary, the problem of water supply assumes increasingly great proportions. Search for water and the installation of water supply facilities present new problems. The demand for water, both for human and industrial consumption, increases daily and frequently compels official agencies to face enormously difficult problems. Such problems were especially encountered in attempting to assure an adequate water supply for industrial plants in mountainous regions where artesian wells could not be drilled. In some places, so-called karst water has been obtained from limestone and dolomite rocks.

In Hungary, the greatest system of connected limestone and dolomite mountains begins at Pilis and reaches across the Dorog mining district, Gerecse, and the Vertes and Bakony Mountains, as far as Keszthely on Lake Balaton. Although in some places the interconnection between limestone and dolomite cannot be traced on the surface, this interconnection continues underground. This fact has been confirmed by the existing karst water level, which may be considered uniform. The northeastern part of the mountain range is limestone and the southwestern part consists of dolomite. Variations in the level of the karst water table are smaller in the limestone masses than in dolomite. In limestone, precipitation drains off into the water table more rapidly, due to the existing spacious caverns. In the wide area between Dorog and Tata, the karst water level was formed mostly at an altitude of 130 to 138 meters above sea level. On the other hand, in the southwestern mountains where dolomite is preponderant, greater differences in water levels are found. For example, the level of karst water at Inota is 124 meters and at Veszprem 220 meters above sea level. The levels of karst water decrease rapidly near the recipients, that is, near Lake Balaton in the south and near the Danube in the north.

Apart from the mountains previously mentioned, an isolated body of karst water exists also in the Mecsek Mountains. Here, the water-blocking schists which were formed beneath the Triassic limestone prevented a large-scale conversion of

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topography into the karst type. The depth of karst wells also differs greatly and, due to the lack of equilibrating conditions, the wells in this region also show immediate response to precipitation. After an unusually abundant supply of water in the spring, the volume diminishes rapidly during the summer months.

The Bukk Mountains in Borsod County present a similarly complicated geological structure and the karst water level is not uniform in this region. Almost every limestone mass has its own karst water level. The levels of the wells in this region vary from 120 to 600 meters above the sea level.

The limestone mountains which contain the Aggtelek Cave in the north have a more uniform structure. Violent processes of conversion into the karst-type topography may have taken place in this limestone mass which has a very great depth. It is possible that an extensive interconnection of karst water may have been formed in this area, including the Josvafo wells at an altitude of 210 to 220 meters.

The temperature of karst wells varies in general between 10 and 14 degrees centigrade. The temperature may be higher in artificially exposed water at greater depths, as for example, in karst water penetrating mines, as well as along the principal line of faults. Thus, the water in the Dorog-Tokod mines has a temperature of 15 to 19 degrees centigrade, at [illegible], 18 to 20 degrees centigrade; and in the Fenyes Well at Tata, 2[illegible] degrees centigrade. The water is relatively hard (carbonate) with an average of 10 to [illegible] degrees of German hardness, although even higher values have been found. Permanent hardness is infrequent in most places. Following heavy precipitation the water in karst wells becomes diluted, that is, the total hardness diminishes.

Prospecting

The methods of prospecting vary according to the peculiar origin and nature of karst water. It is known that water is not distributed uniformly in limestone, but flows in galleries. For this reason, the galleries beneath the karst water level must be located. Galleries and subterranean streams can be exposed by means of drilling or by sinking a shaft. The method employed depends on economic considerations and the amount of water required. In any event, the initial point of operation must be located at a fault [illegible] beneath the karst water level. Experience has shown that the rocks are generally more brittle near fault lines and that cavities are usually formed there. As a result, the existence of water along fault lines is more probable than elsewhere. If drilling is employed, the fault lines should be selected at the greatest depth possible, because in this case the water is under great pressure and pumping is thereby facilitated.

If a shaft is sunk, it will also be necessary to penetrate as deeply as possible beneath the level of the karst water table, but in such cases pumping problems will set a limit. The most ideal situation exists when drilling is employed to a maximum depth of 7 meters. If the water yield should be unsatisfactory at this depth, horizontal prospecting for galleries must be employed to expose as many water-bearing cracks as possible.

In limestone it may be necessary to drill through perfectly dry rock, even at a great depth below the karst water level, to obtain a sudden powerful rush of water from a cavern. In dolomite, on the other hand, a rather slow but continuous flow of water may be expected. Water seepage through dolomite is relatively insignificant.

If surface conditions permit the fault lines to be located, where water is most likely to be found, the most promising procedure is to drill in a direction vertical to the direction of the principal fault. If the direction of the karst water flow is known, drilling should be vertical to the direction of the flow.

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The principal direction of flow is usually found near the highest point of the mountain where precipitation is heaviest and also along natural drainage lines.

Dried-out traces of a rivulet on the face of a cliff, in a stone quarry, or on some other exposure occasionally furnish a very reliable guide and lead to important discoveries. For example, while prospecting for karst water to supply the new waterworks at Heviz, traces of corrosion along the wall of a stone quarry led to the location of a source which yields 2,000 liters of fresh water per minute from a moderate depth. This source now supplies Hungary's largest health resort with excellent drinking water. In another case, active galleries in the Bukk Mountains were located by sinking a shaft at the site of an old dry well. This source, which yields over 4,000 liters of water per minute, will assure the water supply for one of the important industrial plants of Hungary.

Geoelectric prospecting, which is the most modern method, offers even greater possibilities. Due to limitations of space, only the methods which will most likely be used in prospecting for karst water will be discussed in this paper.

The simplest and most useful method is based on measuring the electrical resistance of the subsoil. The essential feature of this method consists in leading a current into the subsoil through two electrodes and measuring the resistance of the soil by varying the distance between the electrodes. The soil is a poor conductor; hence, the current will arch downward and pass through the lower strata on its way to the other electrode to complete the circuit. The greater the distance between the electrodes, the deeper is the penetration of the current. This method is used to register the resistance of the deeper layers. The "apparent specific" resistance is represented as a function of the distance on the graphic chart. The segment of the curve where the resistance drops abruptly indicates the location of the cracks. However, since decreases in resistance are often due to other causes, such as the presence of metals, evaluation of the curves must be made by an experienced hydrogeologist.

It may be noted that water in the upper strata, being at that point relatively free of dissolved substances, offers greater electrical resistance than hard water at a greater depth. Therefore, karst water may be definitely located by this method.

The appended figure represents a cross section of the Zirknitz karst basin and shows the resistance of the moist humus layer along the upper level. A karst duct, through which the water descends, is shown at the depth of 50 meters, while the karst water table may be observed at a depth of 60 meters.

The capacity-difference method enables the researcher to detect the presence of karst water at a maximum depth of 10 meters. In this case, the capacitance of a dipole antenna attached to an oscillator is measured with respect to the surface. The antenna is then uncoupled and tuned to resonance on a rotating plate condenser; i.e., the capacitance difference necessary to compensate for the antenna is measured. This process is repeated at different places, always with identical antenna heights. Changes in the capacitance difference permit conclusions with respect to the electrical discontinuities present in the subsoil. These discontinuities often indicate the presence of karst ducts. Measurements taken along a single line by plotting two different maxima furnish a clue to the likelihood that water is present. A well was sunk at the point of the larger maximum, with the result that the water-carrying gallery was actually located at a depth of 6 meters. This process was then repeated while employing three different antenna heights and the maxima were obtained in the same place in each case.

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In the test used to measure the changes caused by the subsoil in the electromagnetic field, high-frequency transmitters excite a frame antenna. The current induced in the receiver antenna, which is very solidly connected with the transmitting antenna, is rectified by a detector and measured by a galvanometer. The electrical discontinuities in the subsoil change the intensity of the electric field. Experiments with a similar apparatus served to locate a well gallery in the Aggtelek cave at a depth of approximately 8 meters. In this instance, a 100-watt transmitter with a wave length of 500 to 1,000 meters was used.

In addition to the electric processes, certain other processes with the help of which gamma radiations may be observed along deep fault lines, are worthy of mention. These processes are important in the search for water when fault lines are covered with recent deposits. According to some experimental observations, the extremely strong gamma rays are capable of penetrating a covering layer several hundred meters thick.

Exploitation of Karst Water

When karst water appears in a natural well, technically suitable enclosures must be built. In building such enclosures, provision must be made for variations in the water yield and for muddying by melting snows. Experience indicates that the higher a point is above the base level of erosion, i.e., the valley, the greater caution must be used in evaluating the water yield of a well. The higher the point of outlet, the greater is the danger that the yield will diminish or that the well will run dry altogether.

Among others, the Pokolforras Well at Tata, which used to yield 500 liters per second, ran dry as a result of lack of precipitation during the winter seasons. On the other hand, Tukorforras Well, located 6 meters lower than Pokolforras. continues to yield water at an even rate. A striking example of the unreliability of wells on karst water levels is the Zamoly Well, 155 meters above the sea level, at the southern foot of the Vertes Mountains. While its water yield used to be as high as 1,000 liters per second under favorable precipitation conditions, it has dried up completely. This resulted from the fact that the karst water table sank below the threshold of the well, due to a decline in precipitation. The Fenyes Well at Tata is not exposed to this danger because it is located at a depth of 20 meters below the karst water table in that region.

Prior to the building of an enclosure, maximum water yields must, therefore, be estimated with a view to providing for the proper drainage of excess water. The yield of some of the karst wells may, at times, increase a hundredfold over normal yields. Unfortunately, due to the lack of data over a long period, the correlation between precipitation conditions and the water yield of wells can be calculated only in extremely rare cases. The National Water Conservation Bureau began recording this data last year; however, the results of the work will not be available for science and for practical use for several years.

For the time being, only the depth of the well may be compared with the connected levels of the karst water table. No unpleasant surprises are to be expected when the level of the well is considerably lower than the karst water table. In the event of approximate correspondence, however, the enclosure must be so planned as to permit the artificial sinking of the threshold of the well in case of need. Threshold sinking should be employed as a temporary measure only, because permanent tapping of the well at a lower level might endanger the natural balance of the existing water economy. It should be understood, of course, that the threshold can be sunk only if no water-blocking layer, such as shale, is present.

Karst water does not always burst forth from the stone directly but may worm its way to the surface through the upper soil. However, if this happens, it is advisable to sink the well-enclosing shaft down to the rock. This method will prevent the water from escaping through another outlet after the housing has been built.

A different situation arises in exposing and exploiting karst water which is suspected to exist at a certain depth. In such cases, the search is conducted by means of drilling or excavation. Drilling is, of course, the more economical method. However, karst drainage ducts, rather than the water table itself, will often be encountered due to the relatively small diameter of even the largest drills. For this reason, good luck is needed in drilling. On the other hand, this disadvantage is offset to some extent by the greater depth to which drilling may penetrate. The water supply is assured if the drill penetrates the dome of a cavern below the level of the karst water table. If only narrow ducts are encountered, these narrow openings may be widened by acidization, which serves to increase the water yield.

The disappearance of the cooling water of the drill below the level of the karst water table is a clue to the existence of a water-carrying cleavage. The absorbing capacity of the bore hole will, in general, indicate the water-yielding capacity. Theoretically, the amount of karst water which can be produced from a single bore hole is equal to this absorbing capacity. In practice, however, this rule applies only when pumping is carried out under the depression which corresponds to the height of the top of the water column at rest during the absorption test. Therefore, the absorption test must be made by means of a tube with a small diameter which will indicate the water level formed during the water injection.

When karst water is explored by means of a shaft, the water-carrying galleries may be tapped below the level of the karst water table by horizontal drifts These increase the mechanical efficiency of the pump units. The cross section of a shaft may be either circular or square. Each has its advantages and disadvantages. The circular cross section may be worked to greater advantage, but is less economical than the square. In general, the circular shaft should be used in places where the rocks are hard and precaution must be taken against falling boulders. In excavation by square shafts, the shaping of corners is time consuming, but shoring is easier. Unfortunately, geologists have not as yet arrived at a unanimous opinion with respect to standard dimensions for well shafts. However, it is not advisable to employ dimensions less than 2.40 by 2.40 meters.

The greatest difficulties in connection with drilled shafts are encountered in sinking the shaft below the level of the karst water table. Minute particles of granulated rock, present in the water, wear off the sensitive bucket wheels of the centrifugal pumps. If it is necessary to penetrate more than 7 meters below the karst water table, that is, beyond the practical suction height, the electric pump unit is exposed to a breakdown which, in turn, may precipitate a flood. There can be no question of using a plunger pump during the drilling operation. Various types of pneumatic pumps, however, are not affected by water containing granulated rock and are not damaged even when penetrating below water. On the other hand, their disadvantage lies in restricted adaptability and in their pressure heads, as well as in their low degree of efficiency.

Serious thought must be given to long-range pumping operation subsequent to the construction work. Construction does not offer great difficulties when a sufficient amount of water is obtained a few meters below the karst water table, but still within the suction height. Even in this case, however, the location of the pump must be selected carefully. The pump unit must be placed at a height where water cannot reach it. However, it must not be placed too high, because the required depression might not be available under such conditions.

Because of the subnormal precipitation during the last few years, the present levels of the karst water table may be considered lower than normal, but not minimal. After winters having heavy precipitation, water levels 2 to 3 meters higher than those prevailing at present may be expected. Consequently, the pumping chamber must be placed at a point at least 3 meters higher than the present karst water table.

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If it is necessary to employ greater depressions, a pump with a long vertical axis may be used. The use of such a pump, however, has practical limitations, due to the length of the axis. If the axis exceeds 14 meters, difficulties arise. In such installations, the motor is located above and the pump below the karst water table. If a still greater depression is required, it is necessary to add a serially connected plunger pump to the pump unit located above the karst water table or, perhaps, several plunger pumps connected parallel to one another.

There is still another way of installing pump units below the karst water table. This may be accomplished by sealing up with concrete the section of the shaft below the karst water table and by pumping the water through a valved pipe. However, the increased depth is also subject to limitations. If, for example, a depression of 20 meters is required, the shaft bottom plate with dimensions of 2.50 x 2.50 meters will be exposed to a pressure of 125 tons.

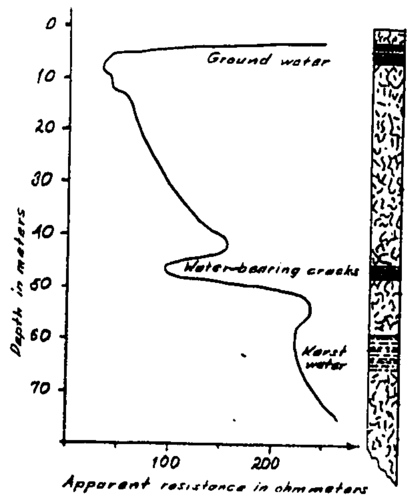
For even greater depths, a combined floating pump might be used. The essential features of this installation include a floating pump which moves between guide rails and drives the water into a basin cut into the side of the shaft. The water is then driven to the surface by a pump of greater capacity, which is solidly mounted in a recess above the karst water table. To avoid the use of flexible tubes, the pressure tube of the floating pump must be long enough to reach the floating height of the pump. The upper part of the pressure tube, which also moves between guide rails, is extended horizontally by a length of pipe. The horizontal extension reaches into a cleavage which is cut into the wall of the shaft and empties above the water basin. While the tube is floating, the cleavage drives the water, which had been pressed upward, into the basin. This process seems uneconomical because it involves loss of altitude; however, it will last only until the floating pump draws off the water to the operational level. Thereafter, the pump unit rests on an iron beam, which steadies it during operation at this level. The stability may be further increased by means of conic pivots.

If the current is broken, the pumping operation stops and the floating pump unit rises to the level of the karst water table under the impetus of the rising water. A control mechanism should be used to synchronize the operation of the pumps. This can be readily accomplished by making use of the variation in the water level of the basin.

It is obvious that all operations involving deep depression pumping give rise to certain technical difficulties. However, the demand for large quantities of water may be satisfied only by tapping karst water at great depths.

[Appended figure follows.]

Diagram of resistance prepared in the Zirknitz karst water basin.



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